Sea Ice Mechanics Research

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Contract #: N00014-98-C-0179

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LONG-TERM GOAL

The ultimate goal of our research is the development of a complete ice dynamics model that will include lead direction and ice thickness distribution in refrozen leads.

OBJECTIVES

NorthWest Research Associates, Inc. (NWRA) objectives during this past year were to conduct the necessary data reduction and analysis of stress data to check the new model and to share the data with Dr. R. S. Pritchard for his use in model development.

APPROACH

Our approach is to use measured sea ice stress and motion to study the behavior of refrozen leads.

WORK COMPLETED

All of the SIMI stress data has been processed to give geophysical stress resultants for comparison with the ice model. One paper has been prepared and presented at the IAHR 14th International Symposium on Ice, in Potsdam, NY.

RESULTS

NWRA's research shows that in the interpretation of sensor oil pressure as ice stress, the two most significant corrections are for the time-dependent behavior of the ice and the thermally-induced stress. Other possible data errors, such as electrical drift correction for gauge temperature variation in the gauge stiffness, were all investigated and shown to be minor in comparison to the effects mentioned.

Thin, circular, oil-filled flat-jack ice-stress sensors were used to measure sea ice stress during ONR's SIMI Program (Coon et al., 1995a; Coon et al., 1995b). These sensors were calibrated in-situ in compression tests at two speeds; rapid loading (around 100 kPa/min.), which produced a square-wave pressure history; and slow loading (around one kPa/min.), which produced a ramp pressure history. The load rate of the ramp tests more closely matched geophysical load rates, while the rapid load rate of the square-wave test is fast enough to measure the elastic response of the ice-sensor system. Based on the test results, it was decided to model the response of the sensor to ice stress with a dynamic or time-dependent type inclusion factor of the form

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Sea Ice Mechanics Research**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NorthWest Research Associates Inc,PO Box 3027,Bellevue,WA,98009-3027**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

$$\sigma = -AP - \int_{t-\tau_0}^{t} BP\,d\tau \qquad \textbf{(1)}$$

where σ is the ice stress normal to the sensor or the air pressure in the air jack, P is the oil pressure in the sensor (with pressure position), and A, B, and τ_o are constants. Elastic inclusion for flat jack gauges for ice are presented by Chen (1981). Hamza and Blanchet (1984) used an incremental analysis for the viscoelastic bridging response of a pressure sensor embedded in an ice sheet. Their approach is similar to what is being done here.

By plotting the air pressure versus the oil pressure found in the square-wave tests, the effective elastic-inclusion factor, A, was obtained for the sensor installed first-year sea ice. In many of these plots, a change in slope occurs at 10 to 20 kPa oil pressure. We judged that the stress sensor readings are unreliable whenever the oil pressure is less than 20 kPa and, therefore, concluded that these sensors do not measure tensile stresses or small compressive stresses. The creep terms in the dynamic inclusion factor, B and τ_o, were determined using the linear up-ramp portion of each ramp test along with the effective elastic inclusion factor from a prior square-wave test at the same installation. The measured air pressure for the whole test was compared with the air pressure calculated from the oil pressure and the model.

The creep model accounts for the effects of the air-jack-loading rate. Although an individual test could be modeled well, the standard deviation of A, B, and τ_o for the eight valid tests was 37%, 57%, and 64% of these values, respectively. The mean values chosen are:

$$A = 2.43 \qquad B = -0.037\ \text{min.}^{-1} \qquad \tau_o = 20\ \text{min.} \qquad \textbf{(2)}$$

Using these mean values, the standard deviation of the calculated value of the maximum air pressure during the eight ramp tests is 64 kPa. The response of one test is shown in Figure 1. The calculated time-dependent response of the stress is shown together with the applied airjack pressure and the reading from the gauge. Figure 1 illustrates clearly why the time-dependent response is important because the maximum applied stress is three times the value read by the gauge. The response in Figure 1 is typical in that the increasing part of the pressure curve is matched better than the decreasing part.

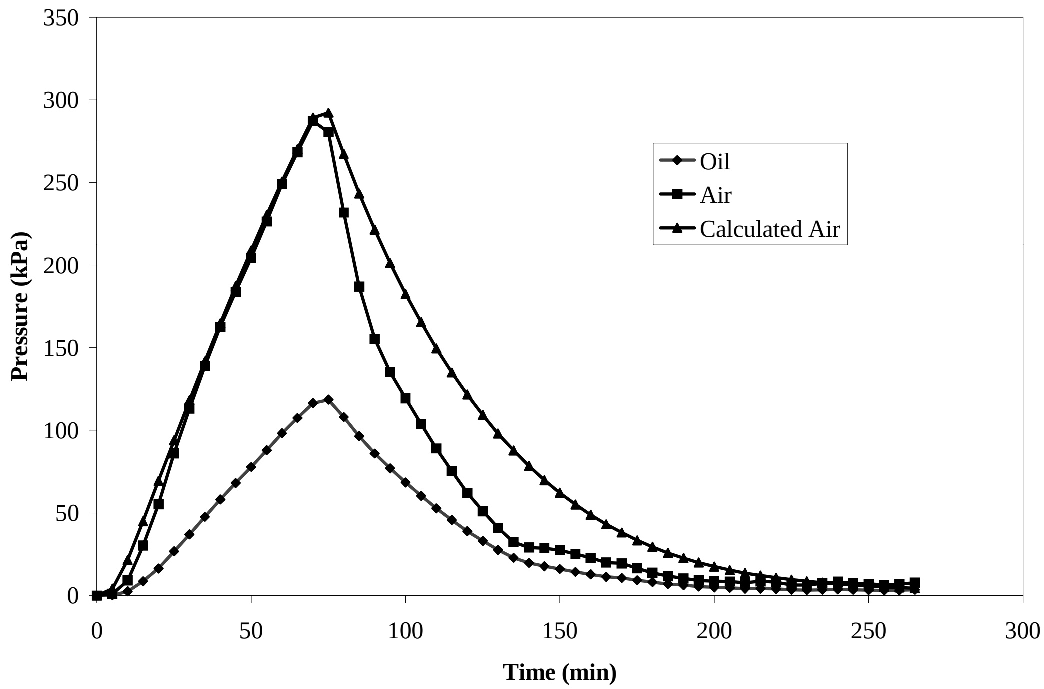

Figure 1. Ramp Test.

A theory for the stresses due to temperature gradients in an unconfined, thick, elastic plate of uniform thickness in which the temperatures and the properties are a function only of depth is given by Timoshenko and Goodier (1951):

$$\sigma_{xx} = \sigma_{yy} = -\frac{\alpha E \Delta T}{1-\nu} + \frac{1}{h(1-\nu)} \int_{-h/2}^{h/2} \alpha E \Delta T dz - \frac{12y}{h^3(1-\nu)} \int_{-h/2}^{h/2} \alpha E \Delta T z dz \quad \textbf{(3)}$$

where x and y are the coordinates in the plane of the plate, z is the coordinate down from the mid-depth of the plate, σ is the stress at z, α is the thermal expansion coefficient, E is the elastic modulus, ΔT is the temperature change from a uniform temperature as a function of z, ν is the Poisson's ratio for the material, and h is the plate thickness. To determine the thermal stress on the stress sensor, the temperature change at the sensor depth was used to evaluate the first term on the right side of Equation (3). For sea-ice, α is essentially constant, and E is taken to be zero for the bottom 20% of the depth, after data from Cox and Weeks (1988). The thermal stress in sea ice is thus

$$\sigma_{xx} = \sigma_{yy} = \frac{\alpha E}{1-\nu} \left\{ -\Delta T + \frac{1}{h} \int_{-0.3h}^{0.5h} \Delta T dz - \frac{12y}{h^3} \int_{-0.3h}^{0.5h} \Delta T z dz \right\} \quad \textbf{(4)}$$

The ice temperatures were measured with thermistors at several depths. To account for the creep out of the thermal stress, the temperature change was calculated not from an initial uniform temperature, but from a reference temperature calculated by smoothing the measured temperatures with a low-pass filter. The filter has a 14-day time constant, which is the same time constant as the slow creep found in the pressurization decay. Constant values of 1 GPa for the effective elastic modulus, 0.3 for Poisson's ratio, and 5.1 x 10^{-5} per °C for the thermal expansion coefficient were found to make the calculated thermal stress, which is the same in all (horizontal) directions, consistent with the ice stress measured

with all four sensors in the rosettes. These values are similar to those used by Lewis (1993) in his calculations of thermal stress in sea ice. Lewis, however, uses a variable elastic modulus, a different definition for a reference temperature, and creep strain in his model. The result of this calculation is illustrated in Figure 2. The effect of ice thickness change has been accounted for. The ice was 76 cm thick on Day -35 and 115 cm thick on Day 57.

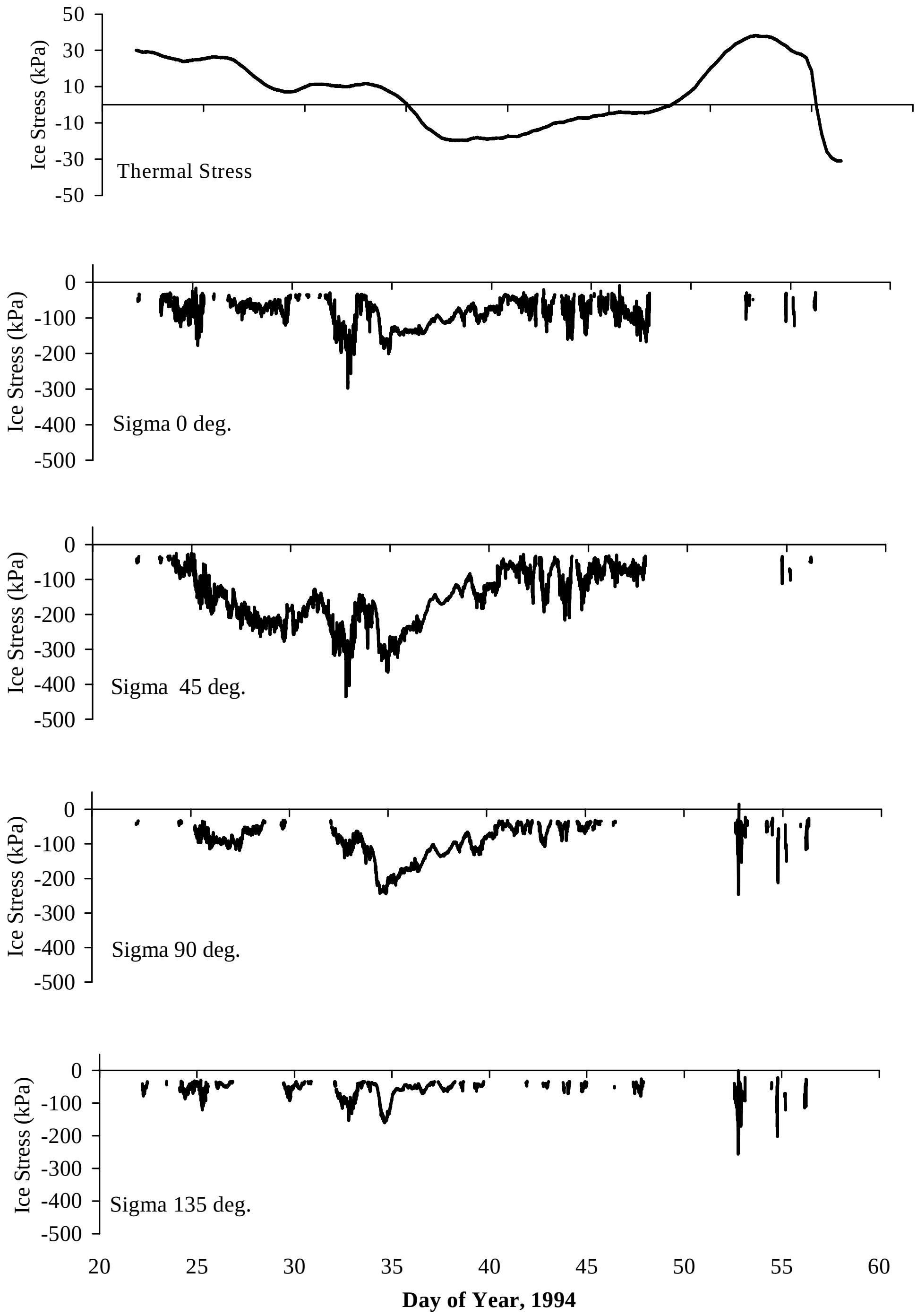

Figure 2. Buoy 3 thermal stress and 4 other stress plots.

IMPACT FOR SCIENCE AND/OR SYSTEMS APPLICATIONS

The anisotropic sea-ice mechanics model can be developed for application to a range of problems, such as assisting in the interpretation of SAR data, forecasting ice conditions, using current SAR data, forecasts of ice-generated noise, studies of climate dynamics, ice loads for offshore platform design, and environmental hazard analysis.

TRANSITIONS

At present, NWRA is using the sea-ice stress data collection and interpreted under ONR programs for evaluating the new ice model.

RELATED PROJECTS

The project is being done together with a project with R. S. Pritchard of IceCasting, Inc. All of the data has been sent to him for his use in model development.

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PUBLICATIONS

Coon, M. D., D. C. Echert, and G. s. Knoke 1998. Stress validation of a failure (yield) surface for pack ice. Proc. 14th International Symposium on Ice, Potsdam, NY, July 27-31, 1998.